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Measuring stone artefact transport: the experimental demonstration and pilot application of a new method to a prehistoric adze workshop, southern Cook Islands

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ABSTRACT

This paper presents a new method, based on the calculation of a Cortex Ratio, capable of contributing towards measures of stone artefact transport in Polynesia. A set of ratios can be calculated by comparing the observed amount of cortical surface area and volume in an assemblage with what is expected should all the products of reduction remain. Because raw material shape and size is controlled for using geometric equations, an estimate for the number of preforms produced from an assemblage also is possible. The method is experimentally demonstrated and applied to an archaeological early stage adze manufacturing assemblage from Moturakau Rockshelter, Aitutaki Island in the southern Cook Islands. Application of the method, in combination with geochemical and chronological analyses, shows that the number of preforms produced and transported, as well as the frequency of their transport, changed over time but the geographic scale of distribution remained the same, essentially local to Aitutaki.

1. Introduction and background

In Polynesian archaeology, the ability to empirically determine the transport of artefacts is important (e.g., Collerson and Weisler, 2007; Kirch et al., 2011; Mills et al., 2010; Weisler, 1998, 2002). However, systemic artefact transport is often difficult to quantitatively reconstruct where only the static results of artefact movement is preserved. This problem can be approached by using the debitage which remains from early stage stone adze manufacture at production sites to determine what was transported away. This study describes a method, designed to measure the number of adze preforms produced and transported, which contributes towards studies that seek to determine the frequency and geographic scale of adze transport (Plog, 1977; Weisler, 1998:521). The method is first experimentally demonstrated and then applied to an archaeological assemblage from the southern Cook Islands.

In Polynesia, stone adzes were a highly maintained and portable tool, manufactured primarily for wood related tasks such as forest clearance, canoe manufacture, timber production and carving (e.g., Bayman, 2003:94–101; Best, 1977; Turner, 2000) but some also had ritualistic and symbolic value (Leach, 1993:40; Spitzer, 2005). Their manufacture involved a number of stages, with initial preform creation often taking place at quarries or workshops, while the final stages of manufacture were frequently carried out elsewhere (e.g., Cleghorn, 1982; Kahn, 1996; McAlister, 2011; Turner, 2011; Turner and Bonica, 1994). Stone adzes were widely moved around Polynesia (Weisler, 1998, 2002, 2008), although typically in small numbers, especially from major quarries such as Tangatatau in Samoa (Leach, 1993) and Eiao in the Marquesas (McAlister, 2011). There are also numerous small-scale quarries throughout Polynesia where lower quality basalts were used by local populations (Allen and McAlister, 2013; Ayres et al., 1998; Kahn et al., 2013; Leach, 1993:36–37; McAlister, 2011). Stone adzes and their debitage therefore represent an ideal data-set from which to reconstruct patterns of artefact transport.

Cultural historical studies (e.g., Duff, 1959; Sharp, 1960) used stone adze morphologies to infer long term patterns of human movement, while technological studies (e.g., Cleghorn, 1982, 1984:409–415; Kahn, 1996; Mintmier, 2007) have allowed inferences about adze transport based on attributes observed in

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debitage assemblages. However, quantitatively reconstructing artefact transport in terms of the number of preforms transported, the frequency of their transport and the geographic scale of their distribution over time, has always posed a challenge (Plog, 1977; Weisler, 1998, 2002). By matching the geochemical signatures of transported adzes with those of their sources, transport distance and direction (i.e., scale) can be demonstrated from quarry source locations to the point of discard (e.g., habitation sites), an approach which has been widely applied in the Polynesia (e.g., Allen and Johnson, 1997; Collerson and Weisler, 2007; McAlister, 2011; Mills et al., 2010; Mintmier et al., 2012; Rolett et al., 1997; Walter and Sheppard, 1996; Weisler, 1997, 1998, 2002, 2008). However, by combining geochemical measures for the scale of adze transport with measures for the number transported and the frequency of their transport, it will be possible to examine interactions, of which adze transport was a part, in greater detail (Weisler, 1998, 2002).

To provide these measures we use a new method, based on the Cortex Ratio (Dibble et al., 2005; Douglass et al., 2008), in an effort to understand adze preform production and transport. This method can provide measures for the number of preforms transported as well as the frequency of their transport over time. We apply this to a Polynesian quarry/workshop where there are well-established chronological controls. Quarry/workshop assemblages are an ideal choice for this application because these assemblages represent the remnants of all the preforms produced at the quarry/workshop and subsequently transported away over a given period of time.

2. Methods

2.1. Method background

The Cortex Ratio is based on measures of stone artefact assemblage surface area and volume. When a stone artefact assemblage is created it is composed of all the products of reduction but, as artefacts are transported away from (or added to) an assemblage, an imbalance in assemblage composition is created. This imbalance can be measured by comparing the *expected* amount of cortical surface area in an assemblage with that which is actually *observed*. The division of these two values produces the Cortex Ratio. If the observed amount of cortex in an assemblage is the same as the expected, the Cortex Ratio equals 1, suggesting that all the products of reduction are present. However, should the observed value differ from the expected, the Cortex Ratio will be a value above or below 1, suggesting that cortex is respectively over- or under-represented. It is anticipated that adze quarry or workshop assemblages will produce values different to 1 because preforms or finished tools were typically transported away from their places of production.

The observed and expected cortical surface area values for the Cortex Ratio can be calculated following two approaches, one experimental (Dibble et al., 2005) and the other archaeological (Douglass et al., 2008). The calculation of observed cortical surface area first requires the surface area of each artefact to be calculated. For all artefacts except cores, this is calculated by multiplying maximum length by maximum width. For cores, a three-dimensional surface area can be calculated by entering the maximum length, width and thickness semi-axes into an equation for the surface area of an ellipsoid (Douglass et al., 2008:518). Maximum dimensional measurements follow definitions outlined by Holdaway and Stern (2004:135–140). Cortical surface area for each artefact is calculated by multiplying artefact surface area by its cortex value. The mid-points of four broad cortex categories for each artefact, 0%, 1–49%, 50–99% and 100% cortex, are used to assign cortex values: 0 (for 0%), 0.25 (for 1–49%), 0.75 (for 50–99%) and 1 (for 100%). Summing the cortical surface area for each artefact provides an observed assemblage cortical surface area.

Calculating expected assemblage cortical surface area requires an estimate of both the average size and shape of the nodules originally selected for reduction. Original nodule size (measured as volume) is obtained by dividing observed assemblage volume by the number of cores (i.e., preforms in adze manufacturing assemblages) present in the assemblage. Observed assemblage volume is the summation of the volume for each artefact in an assemblage where the volume of each artefact is acquired through division of its weight (in grams) by the raw material density calculated following Berman (1939). Original nodule shape is defined by entering the estimate for original nodule volume into a geometric surface area equation to calculate original nodule (cortical) surface area (see Dibble et al., 2005:549).

Finally, to calculate the expected amount of cortical surface area that should be present if all the products of reduction remain in the assemblage, estimated nodule surface area is multiplied by the number of cores (or preforms). Dividing the observed assemblage cortical surface area by the expected produces the Cortex Ratio.

This method has successfully been applied to flake and core assemblages from surface scatters in western New South Wales (Douglass et al., 2008; Douglass, 2010; Holdaway et al., 2008; Holdaway and Fanning, 2014) and Egypt (Holdaway et al., 2010; Phillipps, 2012) as well as stratified assemblages from southwestern Tasmanian cave sites (Ditchfield, 2011). In addition, separate studies support the accuracy and precision of the method via assessment in more controlled environments (Dibble et al., 2005; Douglass, 2010; Douglass and Holdaway, 2011; Lin et al., 2010; Parker, 2011). The present study is the first application of the method to an adze manufacturing assemblage aimed at evaluating its flexibility and applicability in comparison to earlier flake and core assemblage applications.

2.2. New methodological issues for adze manufacturing assemblages

Polynesian tool manufacturers used a variety of raw material shapes for adze production including whole cobbles, large cobble flakes, naturally tabular dike stone and, in some cases, quarried material (see Cleghorn, 1984:56–58; Turner, 1992:68–69; Turner, 2000:38–60). Because an estimate of average raw material shape is required to calculate the expected value for the Cortex Ratio, it is important to use raw material shape equations which represent the shapes utilised by adze manufacturers in the past. Dibble et al. (2005:549) provide equations to calculate surface area from the volume of a sphere, cube or cylinder. A sphere equation is appropriate in a situation where preforms were created directly from cortical cobbles, while a cube equation is appropriate when preforms are created directly from cortical tabular blocks.

At Moturakau, the case study presented here (see below), the adze manufacturing assemblages (debitage and preforms) were created from flake blanks. Flake blanks are typically a large flake removed from a parent stone by the application of force (see Cleghorn, 1982:56–58, 170; Turner, 2000:38–60, Turner, 2011:61). Turner (1992:69–70) provides a definition of the term "blank" in relation to adze manufacturing. According to Turner, blanks are specimens of stone specifically selected for adze preform manufacture but remain, as yet, unmodified or minimally so. Following Turner, a flake blank is only one type of blank (others include naturally occurring cobbles or dikestone chunks) but, most importantly, however a flake blank is produced, it will possess both an inner ventral surface without cortex and an outer dorsal surface that can have cortex. As a consequence, a method for calculating the cortical surface area of a half-sphere (where only the outer dorsal

surface of the half sphere can be used to calculate cortical surface area) is required.

An experimental adze manufacturing assemblage was created to test the applicability of the Cortex Ratio methodology to adze manufacturing assemblages produced from flake blanks. Twelve greywacke cobbles from Kaiaua (Coromandel Coast, New Zealand) were split in half, producing a total 24 flake blanks. Ten preforms were successfully manufactured from the experimental flake blanks (Fig. 1) producing 773 artefacts (including the preforms themselves). Each artefact was measured following the method outlined above with flake preform surface area calculated in the same way as flakes. A sample of 56 greywacke artefacts provided an average density of 2.65 g/cm^3 ($\pm$0.18 g/cm^3). For the purposes of this experimental analysis, preforms were only minimally reduced to resemble a typical Polynesian preform. This also increased the success rate from a limited sample.

2.3. *Calculating the surface area and volume of a half-sphere*

Calculation of the original flake blank cortical surface area requires an estimate of flake blank volume adhering to a half-sphere shape which itself requires flake blank weight (to convert to volume following Berman's (1939) method). This can be approached using flake blank mid-point area (maximum width multiplied by maximum thickness), which is likely to increase as flake blank weight increases; as a consequence, it is possible to develop a formula using a single linear regression analysis to predict weight using the mid-point area.

To test this relationship and develop these formulae two separate preform samples were generated where both mid-point area and weight were known. One was generated from the experimental flake blank assemblage and the other from the archaeological assemblage from Moturakau (described below). Preforms were selected because they provide the closest approximation of the original size and shape of flake blanks in quarry and/or workshops assemblages and so are the best choice to test the predictive power of this relationship in the absence of flake blanks.

Each sample was tested for a normal distribution prior to regression analysis and the resulting regression residuals (Figs. 2 and 3) were examined (Shennan, 1997:156–159). The experimental sample consisted of ten preforms, where both preform mid-point area and weight were normally distributed and so were entered into the regression analysis without transformation. Although the number of preforms available was limited, the resulting residual plots show no internal patterning (Fig. 2) and the results suggest a significant correlation between preform mid-point area and weight (r^2 = 0.76, standard error = 0.084, p = <0.001). The resulting formula is:

$$y = -546.64 + (x) \times 0.43$$

where y = weight and x = preform mid-point area. The preform sample generated from the archaeological assemblage for this study contained only two preforms; therefore the sample was expanded to include all complete preforms recorded from the remaining unmeasured portion of the archaeological assemblage from Moturakau (see Allen, 1992:257). Preforms which suffered

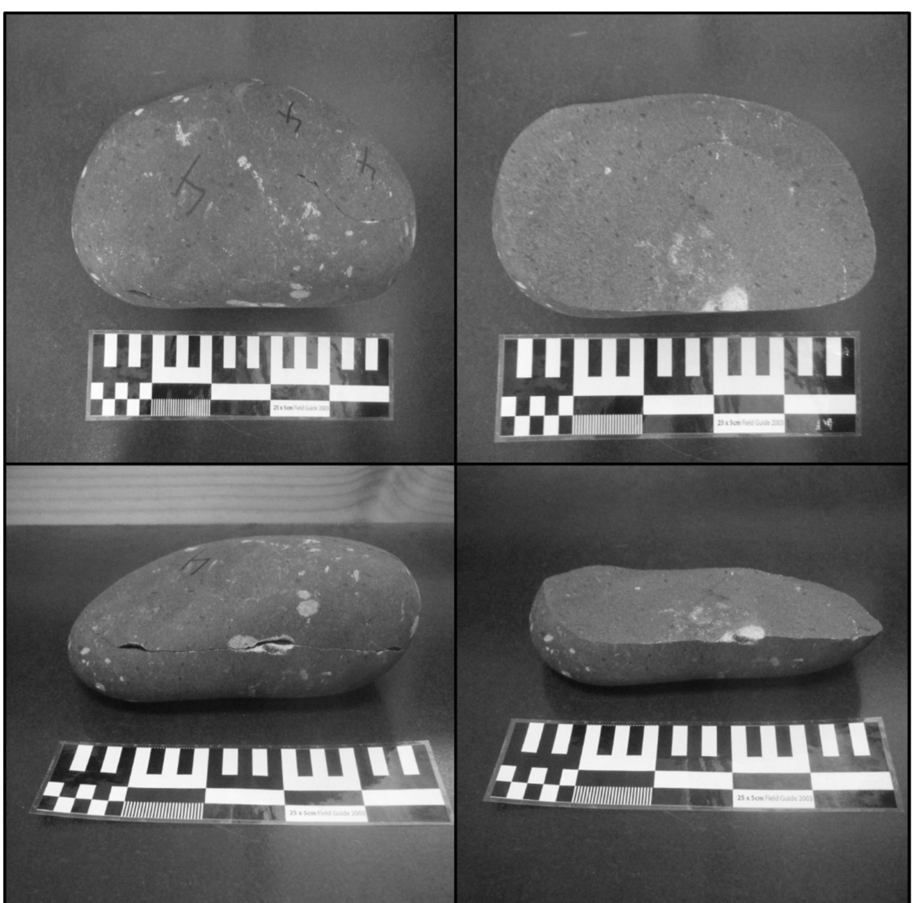

Fig. 1. An example of a cobble (Cobble 4) from Kaiaua and a flake blank produced from the cobble once split.

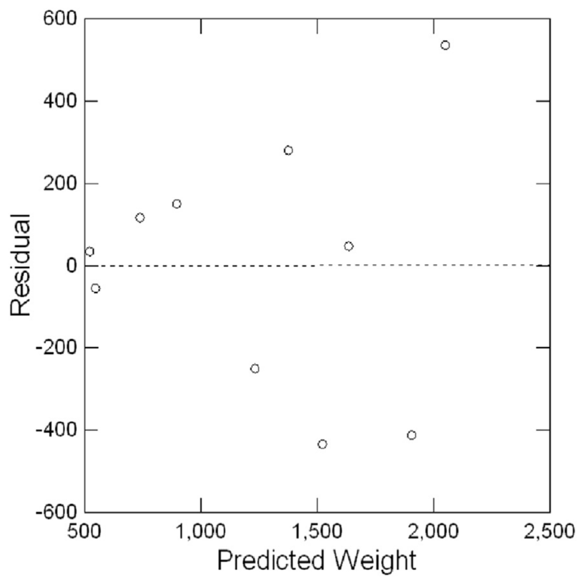

Fig. 2. A plot of residuals from the experimental preform sample against predicted values for weight (g) for preforms where mid-point area (mm^2) is used to predict weight.

transverse fractures, showed signs of breakage or workshop recycling (*sensu* Turner, 2011) were excluded from this analysis (a total of seven broken preforms) as these are unlikely to reflect original flake blank size. This left an archaeological sample of eight preforms.

Neither archaeological preform mid-point area nor weight was normally distributed so these values were transformed by their natural logarithms to obtain a normal distribution. The regression analysis demonstrated a significant correlation between preform mid-point area and weight ($r^2 = 0.87$, standard error $= 0.252$, $p = <0.001$), while the residual plots suggest the assumptions of the test were not violated (Fig. 3). The resulting archaeological formula is:

$$\log(y) = -4.963 + (\log(x)) \times 1.403$$

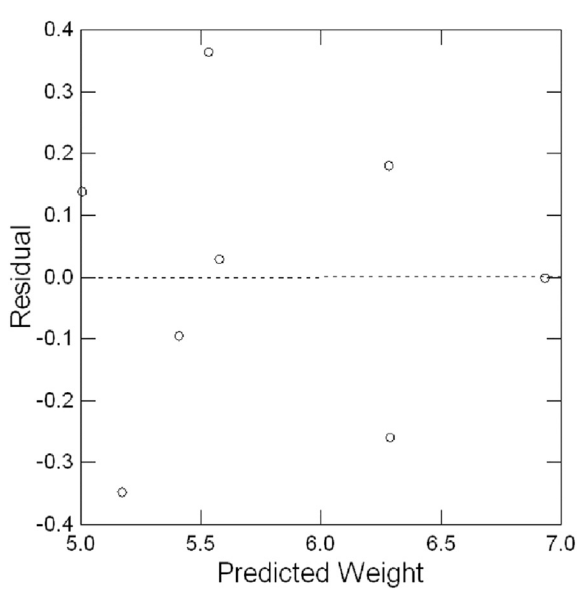

Fig. 3. A plot of residuals from the archaeological preform sample against predicted values for the natural logarithm of weight (g) for preforms where the natural logarithm of mid-point area (mm^2) is used to predict weight.

where $\log(y) =$ weight and $\log(x) =$ preform mid-point area. To test the predictive accuracy and precision of both formulae, predicted weights using these formulae were compared against known weights for preforms from both the experimental and archaeological assemblages (Tables 1 and 2). In both cases, there is no statistically significant difference between the actual and predicted preform weights. As such, these formulae were used as a base to predict flake blank weight for volume.

However, before these regression formulae are used to calculate flake blank weight, flake blank mid-point area must be reasonably estimated while adhering to a semi-spherical shape. In the experimental assemblage, the minimally reduced preforms lost close to 60% of their width but very little of their thickness during reduction, which is in line with results from other studies (e.g., Turner and Bonica, 1994). As such, the width of each preform can be proportionally increased by 60% (30% either side) and thickness retained to conservatively estimate original flake blank mid-point area prior to reduction. However, entering this mid-point area into the regression equation for weight to derive volume at this point is still problematic because the next step involves calculating cortical surface area based on a geometric equation using the volume estimate. This equation would still treat the entire surface area as cortical, whereas we know that flake blank ventral surfaces are non-cortical.

To solve this problem, the flake blank mid-point area can initially be treated as a sphere (Fig. 4) where, instead of retaining thickness as was the case for the half-sphere, thickness is doubled in addition to increasing width by 60%. This enlarged mid-point area is then entered into the regression equation to derive weight. Weight is divided by material density for volume and the sphere shape defined, and cortical surface area obtained, when volume is entered into an equation for the surface area of a sphere:

$$S = 4\pi(3V/4\pi)^{2/3}$$

where $V =$ volume. Because the resulting sphere surface area is double the size of the semi-spherical flake blank (Fig. 4), it is halved to arrive at the estimated semi-spherical flake blank cortical surface area. This will not include the ventral surface. When the experimentally predicted values for estimated flake blank cortical surface area are compared to the actual values recorded before reduction from the experimental flake blanks, there is no statistically significant difference (Table 3). This demonstrates that this method is capable of accurately estimating original flake blank cortical surface area and volume. Although a half sphere may not exactly reflect flake blank shape in all cases, it should serve as a good approximate

Table 1
Comparison of the known weights with weights predicted by the regression formula developed from the experimental assemblage. There is no statistically significant difference between known weights and predicted weights ($t = 0.011$, $df = 9$, $p = 0.992$). Cobbles are indicated by number, while the flake blanks they produce are identified by letter.

ID	Cobble	Flake blank	Weight (g)	Mid-point area (mm^2)	Predicted weight (g)
1	1	A	558.1	2484.84	524.33
131	3	A	1089.6	4803.18	1523.53
363	6	A	1683.7	5064.86	1636.31
514	7	A	2587.0	6026.68	2050.86
631	9	A	1048.2	3352.91	898.46
680	12	A	493.1	2542.20	549.05
748	10	C	855.6	2985.47	740.09
804	8	B	1494.0	5690.50	1905.96
908	10	A	1657.0	4463.78	1377.25
978	12	B	984.0	4131.52	1234.04
Mean			1245.03		1243.99

Table 2
Comparison between the known weights and weights as predicted by the regression formula developed for the archaeological preform assemblage. There is no statistically significant difference between known weights and predicted weights ($t = 0.170$, $df = 7$, $p = 0.870$). 'ID (1992)' refers to the artefact accession number assigned by Allen (1992).

ID	ID (1992)	Weight (g)	Mid-point area (mm^2)	Predicted weight (g)
432	NA	415.5	3048.99	540.59
1559	MRI-4-9-27	171.6	1222.50	149.97
1560	MRI-13-6-404	203.2	1628.85	224.32
1561	MRI-4-7-337	641.1	3036.54	537.49
1594	MRI-10-11-276	272.3	1836.96	265.54
NA	MRI-2-Fe3-93	364.0	1779.08	253.88
NA	MRI-4-6-79	124.7	1376.94	177.21
NA	MRI-7-10-304	1024.0	4827.68	1030.11
Mean		402.05		397.39

measure. As Dibble and colleagues demonstrate (2005:552–554), variances in nodule shape and size must be deviate by more than 25 percent to significantly affect the result produced by the Cortex Ratio methodology.

2.4. Cortex Ratio: experimental application

Since the first flakes removed during adze preform manufacture will be disproportionally cortical the majority of cortex should remain in adze quarry assemblages (Cleghorn, 1982; Turner and Bonica, 1994), while a large portion of assemblage volume (i.e., the preforms) will be removed. This will result in an over-representation of cortex in the assemblage that remains. To test whether the Cortex Ratio (using the half-sphere calculation) accurately reflects this, Cortex Ratios were calculated as preforms were removed from the experimental assemblage (Table 4). As predicted, when preforms are removed, the Cortex Ratio gradually rises reflecting the over-representation of cortex in the assemblage. When no preforms are removed from the experimental assemblage, the Cortex Ratio is close to 1 (Table 4). This demonstrates that the Cortex Ratio is sensitive to artefact transport.

2.5. Volume Ratio and experimental demonstration

As preforms are removed, it is also true that observed assemblage volume will decrease relative to the expected amount of

Table 3
Comparison between estimated flake blank surface areas and volumes against their known values recorded prior to reduction in the experimental assemblage. There is no statistically significant difference between the estimated and the original flake blank surface area ($t = -0.421$, $df = 10$, $p = 0.683$) and the estimated and the original flake blank volume ($t = -1.627$, $df = 9$, $p = 0.138$). Original flake blank volume was not recorded for 12B. Estimated flake blank volume is calculated via the method specified in-text for the Volume Ratio.

Cobble	Flake blank	Estimated flake blank surface area (cm^2)	Original flake blank surface area (cm^2)	Estimated flake blank volume (cm^3)	Original flake blank volume (cm^3)
1	A	255.62	239.85	404.72	331.47
3	A	420.53	338.22	878.54	758.49
6	A	437.01	351.32	932.02	961.51
7	A	495.14	409.95	1128.60	1432.45
9	A	322.28	403.85	582.13	1554.72
12	A	260.28	350.10	416.44	831.32
10	C	294.99	464.07	507.03	508.60
8	B	475.23	470.07	1059.89	1083.77
10	A	398.65	464.07	809.17	779.25
12	B	376.63	350.10	741.27	NA
Mean		373.64	384.16	745.98	915.73

volume. Consequently, if a Volume Ratio is calculated, it will show the opposite pattern to the Cortex Ratio as preforms are removed. A Volume Ratio can be calculated like the Cortex Ratio using an observed and expected value for volume (see also Ditchfield, 2011; Phillipps, 2012 for different approaches). The method for calculating observed volume (as part of the expected cortical surface area calculation) is established above (summation of the volume for each artefact in an assemblage) but a method for calculating expected assemblage volume, also using estimates for flake blank size and shape, is required.

Original flake blank size can be calculated using the same mid-point method used for the Cortex Ratio but, because volume is now the unit of interest rather than surface area, flake blank shape must be calculated differently. For a Volume Ratio, flake blank shape is approximated by entering the enlarged 'spherical' mid-point area (width increased by 60% and thickness doubled) into an equation for the area of an ellipse:

$$\text{area} = \pi ab$$

where a = horizontal radius (width) and b = vertical radius (thickness). The radius values are taken as half of the enlarged width and thickness values. Weight and volume for this shape are

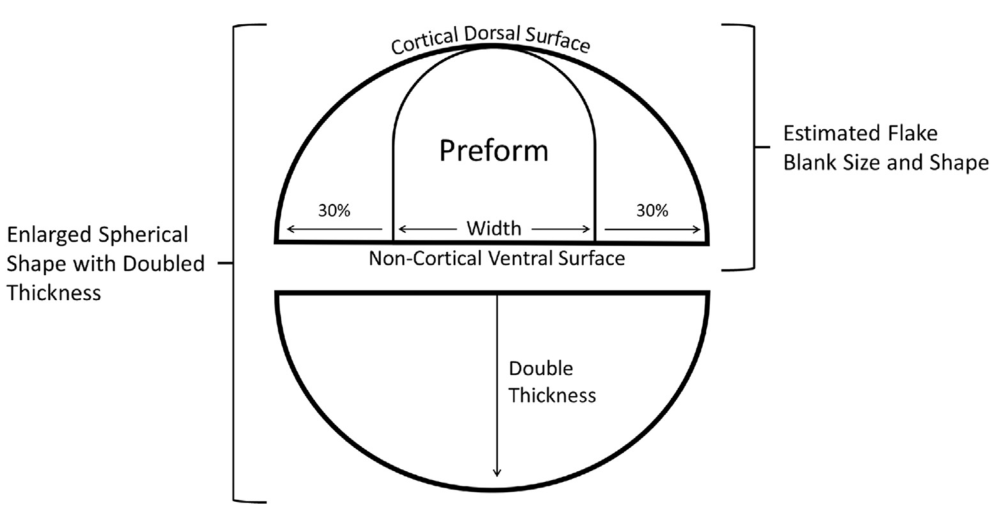

Fig. 4. Diagram showing the procedure to calculate estimated flake blank surface area using a sphere shape twice its size.

Table 4
Changes in Cortex Ratios as preforms are sequentially removed from the experimental assemblage.

Preforms removed	Cortex Ratio
0	1.04
1	1.13
2	1.25
3	1.41
4	1.56
5	1.80
6	2.24
7	2.90
8	4.29
9	8.03

derived from the regression equations, as for the Cortex Ratio, and divided by two to estimate the semi-spherical flake blank size. Both rectangular and spherical mid-point shape equations were trialled but the formula for an ellipse provided the most accurate results. The accuracy of this volume calculation is shown in Table 3 where there is no statistical difference between predicted flake blank volume and original flake blank volume.

Finally, to calculate expected assemblage volume for the Volume Ratio, the obtained value for flake blank volume must be multiplied by an estimate of the number of flake blanks used to produce the assemblage. This is problematic because flake blanks were reduced and removed from quarry/workshop assemblages as preforms. However, because most of the cortical surface area from their reduction remains in early stage adze manufacturing assemblages (*sensu* Cleghorn, 1982; Turner and Bonica, 1994), an estimate for the number of flake blanks used to produce the assemblage can be based on a division of observed cortical surface area by the estimate for flake blank (dorsal) surface area. This assumes that most of the cortex actually does remain in the assemblage and that flake blank dorsal surfaces were fully cortical prior to their reduction. Using this estimate, expected assemblage volume may be calculated and divided by observed volume to give the Volume Ratio. Both the Volume Ratio and the estimate for the number of flake blanks were tested experimentally by removing preforms sequentially from the experimental assemblage, with both values calculated at each removal (Table 5). This shows that, as expected, the Volume Ratio decreases as preforms are removed and is sensitive to artefact transport.

In cases where preforms retain cortex when removed from an early stage adze manufacturing assemblage, or when the flake blank dorsal surfaces were only partially cortical prior to reduction, the estimate for the number of flake blanks will become too low, such that expected assemblage volume would also be too low, thereby affecting the Volume Ratio. This effect is visible in Table 5 where the number of flake blanks responsible for assemblage creation becomes less accurate as more preforms are removed because some of these retain a small portion of cortical surface area.

In such a situation, estimates for the number of flake blanks must be made without relying on cortex assumptions. This can be achieved by estimating the amount of volume removed using the estimated number of flake blanks (initially based on the above cortex assumptions) minus the number of preforms remaining in the assemblage. Multiplying this figure by average preform volume (469.82 cm^3 in the experimental assemblage) will then provide a rough measure for the amount of volume removed from the assemblage by transport behaviour. We know that this amount will be lower than the actual value (because it is based on an estimate for the number of flake blanks which is too low) but, when it is added to observed assemblage volume and divided by estimated blank size (745.98 cm^3 in the experimental assemblage), the estimated number of flake blanks will be significantly improved. Using this improved estimate, expected assemblage volume and, subsequently, the Volume Ratio can be recalculated. This adjustment is also applied to the experimental assemblage simulation (Table 5) where both the estimated number of flake blanks and the Volume Ratio are substantially improved. The number of blanks becomes consistently accurate to within one flake blank.

2.6. Calculating the number of transported preforms

Finally, the number of preforms produced and transported away from the assemblage can be estimated simply by subtracting the number remaining in the assemblage from the calculated total number of flake blanks. This assumes one preform was manufactured per flake blank. As such, the results provided by this method can generate measures for the production and transport of preforms from quarry/workshop assemblages. Cleghorn (1982, 1986) provides a similar measure of preform production and transport at Mauna Kea, achieved by using an experimentally derived standard weight ratio. The method presented here builds on Cleghorn's research by accounting for raw material size and shape using shape geometric equations.

Table 5
The Volume Ratio, the estimated number of flake blanks responsible for assemblage creation and their corrections when cortex assumptions do not hold as preforms are sequentially removed from the experimental assemblage. The original number of flake blanks is 10.

Preforms removed	Estimated number of flake blanks	Volumetric ratio	Improved no. of flake blanks	Improved Volume Ratio
0	10.38	1.01	10.73	0.98
1	10.15	1.01	10.93	0.93
2	10.04	0.96	10.94	0.88
3	9.87	0.89	10.61	0.83
4	9.35	0.80	9.60	0.78
5	9.02	0.77	9.50	0.73
6	8.96	0.75	9.84	0.68
7	8.71	0.72	9.88	0.64
8	8.57	0.64	9.66	0.57
9	8.03	0.58	9.11	0.51
10	7.72	0.54	9.05	0.46

3. An archaeological application

A small rockshelter workshop on the islet of Moturakau, within the lagoon of the "almost-atoll" (*sensu* Stoddart and Gibbs, 1975) of Aitutati, southern Cook Islands (Fig. 5), was selected for the pilot study. Moturakau is one of two tiny volcanic remnants (the other being Rapota Islet) within the Aitutaki lagoon and is located near the southern boundary. Measuring 460 by 120 m, and lacking a permanent water source, Moturakau Islet was likely occupied on a short-term basis by people engaged in adze manufacture and marine extraction activities (Allen, 1992). The islet is dominated by a 9 m high ridge of bedded agglomerate tuff, which incorporates blocks of relatively fine-grained nephelinite basalt. The rockshelter workshop is located on the leeward side of this tuff ridgeline and preserves evidence of early stage adze manufacturing within a stratified and chronologically well controlled context (Allen, 1992; Allen and Morrison, 2013). Altogether more than 17,000 basalt artefacts (mostly un-utilised flakes) and 15 preforms (both broken and complete) were excavated. Flake blanks produced from basalt cobbles and boulders were the main raw material for preform manufacture, as indicated by both modified surface materials (e.g., Fig. 6) and the flat, non-cortical ventral surfaces of almost all of the 15 excavated preforms (Allen, 1992:290). The repeated use of

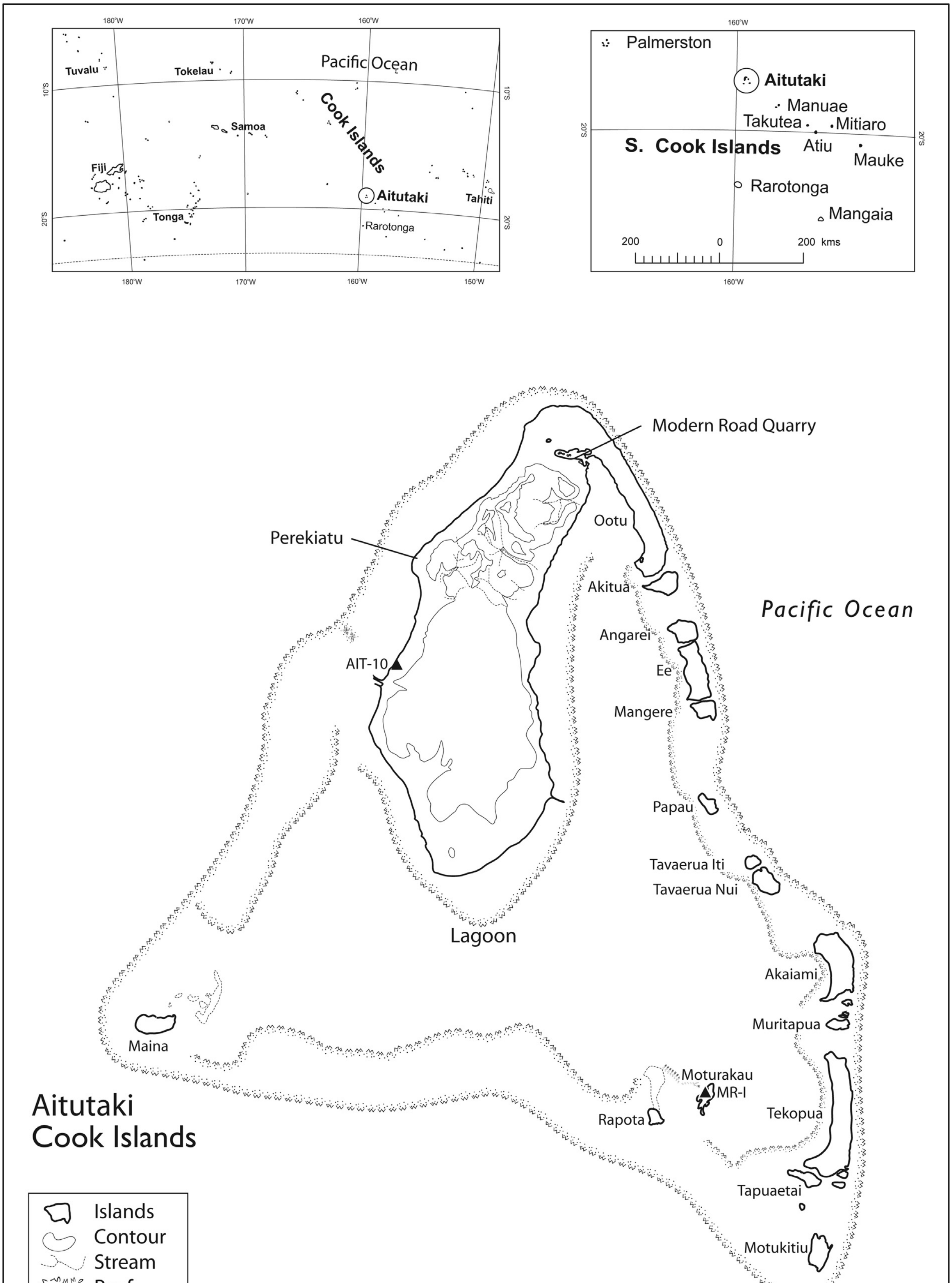

Fig. 5. Map of Aitutaki showing the location of Moturakau and Rapota Islets, Moturakau Rockshelter (MR-1), and other places mentioned in the text.

Fig. 6. An example of a flaked boulder from Moturakau.

these boulders as a source for flake blanks has resulted in a loss boulder cortex overtime meaning that not all flake blanks were reduced from a fully cortical state at Moturakau. This is also apparent in the initial results (see below). Evidence for adze manufacture also is found on nearby Rapota Islet, where raw materials are more plentiful (Allen, 1992; Di Piazza and Pearthree, 2003).

The nephelinite basalt of Aitutaki is fine-grained but of lower quality than other commonly exchanged sources in Polynesia (e.g., Tangatatau Quarry in Samoa), being characterised by a moderate abundance of olivine inclusions. There is little evidence for its transport beyond Aitutaki but basalt from Moturakau and/or Rapota was transported to several nearby coralline islets (e.g., Tapuaetai) for further reduction (Allen, 1992:123). It is also possible that material from Rapota was moved to Moturakau where the rockshelter provided a protected workspace. Further, two fine-grained adzes from Moturakau were geo-chemically matched to Samoan sources, while several extra-island sources are also represented at the Ureia site on the Aitutaki mainland (Allen and Johnson, 1997). Adze quality basalts are also found on the Aitutaki mainland, at the traditionally known quarry site of Perekiatu (Buck, 1927) and at the modern road quarry on the northern end of the mainland (Allen and Johnson, 1997:119); both sites have been heavily modified by modern activities.

The assemblage analysed here derives from a 16 m^2 excavation in and adjacent to Moturakau Rockshelter (MR-1) undertaken in the late 1980s (Allen, 1992; Allen and Morrison, 2013) (Fig. 7). Twelve main strata were differentiated on the basis of sedimentological characteristics and are referred to here as analytic Zones A through K (top to base). Although most strata represent human activities, some units resulted from marine intrusions, probably associated with storm events; these were more common in the lower half of the shelter deposit. Zone E was a particularly thick unit of marine sand containing archaeological materials in secondary context. Lensing and upward fining within this unit suggests it

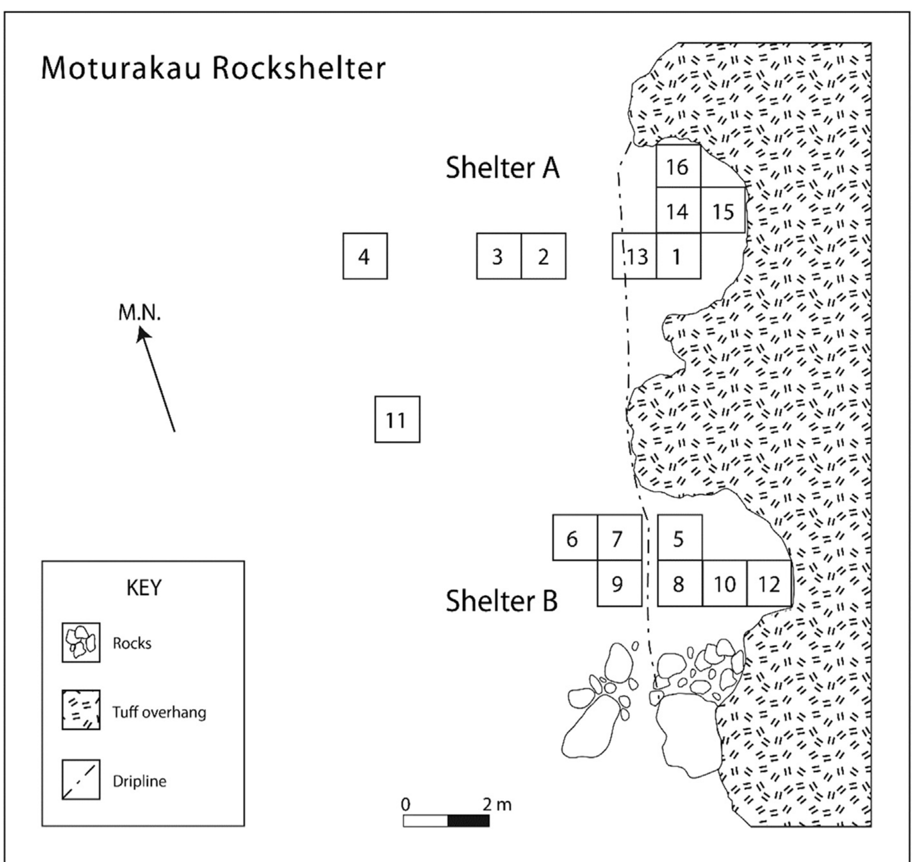

Fig. 7. Map of Moturakau rockshelter (MR-1) showing placement of the excavation units.

represents a single short-lived high-energy event. Recently, new AMS dates on short-lived (10 yrs or less) and medium-lived (10–75 yrs) materials (after Allen and Huebert, 2014), were combined with a Bayesian analysis of the entire series of 21 radiocarbon determinations. The results point to shelter use from approximately the 12th century AD onward and extending into the historic period (Allen and Morrison, 2013). Table 6 provides Bayesian-derived age and maximal duration estimates for each analytic zone.

The excavations followed the natural site stratigraphy and particularly thick layers were sub-divided into arbitrary 10-cm levels or spits. All excavated sediments were minimally processed in the field with ¼ inch mesh (6.4 mm) screens, while a sample of excavation units were processed using finer screens to recover faunal remains. Small fire features were common within the deposit, as were archaeofaunal remains (mainly fish) and evidence of shell fishhook production. Debitage from adze preform manufacture occurs throughout the deposit but is particularly abundant in Zones F and D.

For this study, all flake debitage of 2 cm or greater from Zones C, D and F of 11 test pits (TP5-10 and TP12-16; Fig. 7) was analysed, a total of 2209 artefacts; smaller reduction flakes, which were common, were omitted from this analysis. Prior research suggests that this number of artefacts represents an adequate assemblage size for this type of analysis (Lin et al., 2010). Two complete preforms derive from the three zones (although, as noted above in Section 2.3, eight complete preforms from the site are used to estimate original flake blank size and shape). Zone E contained basalt artefacts but materials in this storm deposit were in secondary context, could be chronologically mixed, and were consequently excluded from this analysis. The Moturakau assemblage was measured in the same manner as the experimental assemblage and the material density was calculated based on a sample of 56 artefacts, returning an average value of 3.12 g/cm^3 (±0.24 g/cm^3).

4. Results

At Moturakau the expectation was that Cortex Ratio values would be *above one*, while Volume Ratio values would be *below one*, because preforms were presumably removed from the islet to other places for further reduction and use. As expected, the Cortex Ratios (Table 7) show results above one, demonstrating that the Moturakau assemblage is disproportionally cortical due to preform removal. Zone F returns a Cortex Ratio of 4.33 while Zone D returns a Cortex Ratio of 11.92. However, the Volume Ratios also return values above one (Table 7). Based on the observations at Moturakau (see above), it is highly likely that flake blanks were reduced from a partially cortical state, with the consequence that, as discussed above, the estimated number of flake blanks responsible for assemblage creation will be too low and will lead to a Volume Ratio that is too high. As such, the corrections discussed above for this type of situation were applied to improve both the estimated number of flake blanks responsible for assemblage creation and the Volume Ratio (Table 8). The corrections produced Volume Ratios below one which is consistent with expectations derived from the experimental work and previous research (e.g., Turner and Bonica, 1994). The new results indicate that all Volume Ratios are equal to 0.64, with little inter-zone variation (Table 8).

It is also possible to produce a measure for the frequency of preform production and transport over-time using zone duration estimates from Moturakau's well dated sequence and dividing these estimates by the number of transported preforms for those zones. Estimates for zone duration are provided in Table 6 based on the Bayesian analysis of Allen and Morrison (2013:4571). The frequency results are displayed in Table 9 and show a slight increase in the frequency of preform production and transport between Zones F and D, while Zone C shows a reduction. Notably, the values produced here only relates to 11 m^2 of the archaeological deposit and does not reflect the total number of preforms produced at this site, although it could be used judiciously to estimate those values.

Table 7
The results for the Cortex and Volume Ratios for each individual zone and all zones combined. No Cortex Ratio for Zone C was produced because no preforms remained in the assemblage. Observed and expected cortex are measured in cm^2 while observed and expected volume are measured in cm^3.

	Zone C	Zone D	Zone F	All Zones
Number of preforms	0	1	1	2
Observed cortex[a]	724.26	2165.84	786.06	3676.16
Expected cortex[b]	NA	181.68	181.68	363.36
Observed volume	2606.72	5591.55	1710.83	9909.11
Expected volume	925.02	2766.19	1003.94	4695.16
Cortex Ratio	NA	11.92	4.33	10.12
Volume Ratio	2.82	2.02	1.70	2.11
Number of blanks	3.99	11.92	4.33	20.23

[a] Standard deviations (±1); Zone C = 618.39, Zone D = 458.9, Zone F = 460.1, All Zones = 482.97.
[b] Standard deviations (±1); Zone C = 16.1, Zone D = 9.22, Zone F = 6.75, All Zones = 9.97.

Table 6
Best age estimates for the Moturakau analytic zones discussed here, based on Bayesian analysis of 16 radiocarbon determinations (data from Allen and Morrison, 2013:4570; three outliers excluded).

Zone	Bayesian posterior possibility (AD)	Number of ^{14}C determinations	Modelled elapsed time
Zone K	1047–1297	1	NA
Zone J	1266–1356	2	1-134
Zone H	1290–1362	3	1-99
Zones F	1329–1435	3	1-95
Zone D	1338–1618	4	1-332
Zone C	1647–1848	1	1-384
Zone B	1701–1941	1	1-193
Zone A	1638–1892	1	1-288

5. Discussion

5.1. Evaluation of the experimental study

The aim of the present study was two-fold. First we sought to develop a method to empirically investigate aspects of adze production and transport. In this regard we showed that a modified version of Dibble et al. (2005) Cortex Ratio is capable of providing useful transport measures when applied to early stage adze manufacturing assemblages which utilised flake blanks. This is aptly shown in Tables 4 and 5 where, when all the products of

Table 8
Improved estimates for the Volume Ratio and the number of flake blanks responsible for assemblage creation from each zone and all zones combined. Estimated flake blank size is 232 cm^3 while average preform volume is 128.86 cm^3. All volume measurements are measured in cm^3.

	Zone C	Zone D	Zone F	All Zones
Number of blanks	11.24	24.10	7.37	42.71
Number of preforms	0.00	1.00	1.00	2.00
Observed volume	2606.72	5591.55	1710.83	9909.11
Number of preforms removed	11.24	23.10	6.37	40.71
Preform volume removed	1448.41	2976.72	820.85	5245.98
Total assemblage volume	4055.14	8568.27	2531.69	15155.09
Improved number of blanks	17.48	36.93	10.91	65.31
Improved Volume Ratio	0.64282	0.64292	0.64304	0.64291

Table 9
A measure of the frequency of preform production and removal over the time spans represented in each of the individual Moturakau zones and all zones combined. The time spans are the maximum estimates derived from Table 7 in Allen and Morrison (2013:4571).

	Zone C	Zone D	Zone F	All Zones
Time span (years)	384	332	95	–
Improved number of blanks	17.48	36.93	10.91	65.31
Number of preforms removed	17.48	35.93	9.91	63.31
Frequency of removal (per/yr)	0.05	0.11	0.10	–

reduction are present, the Cortex and Volume Ratios approximate 1, while when preforms are removed from the assemblage the ratios respond accordingly. As such, the total amount of transported cortex and volume is quantified by a ratio of its over- or under-representation. Along with the amount of volume and cortex transported, the experimental results (Table 5) also show it is possible to accurately estimate the number of preforms produced and transported based on principles of geometry which take into account raw material shapes and sizes.

5.2. Analytical implications of archaeological pilot study

The study's second aim was to evaluate the method's utility for empirically reconstructing adze production and transport in an archaeological context. Moturakau, with a large adze manufacturing assemblage from a stratified and well-dated archaeological context was used for the pilot study. Application of the method to the Moturakau assemblage demonstrated not only that the method is archaeologically applicable but also the importance of considering raw material form and its effects on assemblage formation prior to analysis. The fact that flake blanks were only partially cortical prior to reduction at Moturakau heavily affected the uncorrected Volume Ratios (Table 7) which partly relied on assumptions that flake blank dorsal surfaces were fully cortical prior to reduction.

Although the evidence suggests that the repeated use of large cobbles and boulders as a source for flake blanks resulted in both the gradual loss of boulder cortex overtime and the use of partially cortical specimens at Moturakau, it is possible other circumstances contributed to this situation as well. Two of the most likely are considered here. First, it is possible that flake blanks were partially reduced at other localities before transport to Moturakau. Di Piazza and Pearthree (2003), for example, note significant reduction activities on nearby Rapota Islet where raw material is plentiful. Second, some boulders or exposures of fine-grained rock may have simply lacked distinctly weathered surfaces. Whatever the case, the Cortex and Volume Ratios were instrumental in identifying the partially cortical nature of flake blank dorsal surfaces at Moturakau, thereby raising new research questions.

Despite the foregoing, the Cortex Ratios (Table 7) still suggest the assemblage is over-represented in cortex. This shows the substantial effect that preform removal had on overall assemblage structure. Such a proportionally large amount of volume was removed by preform transport that the cortical surface area remaining in the assemblage became disproportionally large in comparison to volume.

Using revised estimates for number of flake blanks used to produce the assemblage resulted in Volume Ratios of 0.64 for each zone (Table 8). These results are consistent with experimentally-derived expectations (Table 5) and reflect the effect that a loss of volume (via preform transport) has on assemblage formation. The lack of inter-zone variability in the Volume Ratios is interesting. In part, this reflects the use of a consistent average flake blank and preform size for the zone calculations. However, the lack of inter-zone variability also points to temporal continuity in patterns associated with the selection and reduction of flake blanks. This notion is supported by inter-zone variation in other critical measures, such as observed volume (Tables 7 and 8), which might otherwise contribute towards variation in Volume Ratios. These patterns could usefully be further assessed by technological analyses.

5.3. New insights into adze production and transport at Moturakau

Due to the amount of preform movement from Moturakau over time, volume is consistently under-represented by at least 36% (i.e., Volume Ratios of 0.64). The cumulative effect, as measured by the method, informs on the total amount of artefact transport from Moturakau as well as the number of preforms transported away. When combined with radiocarbon ages from these zones (Table 6), results (Table 9) show that the frequency of artefact transport was greatest during the Zones D and F occupations but the duration of these zones was different. The early occupation (Zone F), placed between AD 1329 and AD 1435, produced 9.91 preforms. The duration of this occupation was, however, relatively short, probably no more than 95 years. Zone D, estimated to date between AD 1338 and AD 1618, produced 35.93 preforms over an occupation potentially as long as 332 years. Although their durations differ, the frequency of artefact transport during the two occupations is similar. The Zone E storm event, which separates Zones D and F, appears to have had little effect on production and transport rates. These results, in combination with the extended time period associated with Zone D (probably a palimpsest of multiple visits), suggests that local adze production increased in mid-prehistory. During Zone C (ca. AD 1647 and AD 1848) it is estimated that 17.48 preforms were produced and transported. While the Zone C occupation (possibly 384 years in length) was similar in duration to Zone D, adze production and transport nearly halved during this period. Although the Zone C artefact content suggests a pre-contact age (i.e., pre-1789 AD), the two sigma age range of the single radiocarbon determination suggests the associated activities could extend into the early post-European period, which saw the introduction of metal tools and Old World diseases; both of these processes could have affected adze production, albeit in different ways.

Finally, geochemical evidence offers insights into the distance the Moturakau preforms travelled. It is likely that the Moturakau preforms were transported relatively short distances, probably only to nearby islets for further reduction, or to the Aitutaki mainland for use. This is supported by geochemical analyses which suggest that adzes manufactured from local basalts become increasingly important over time, while extra-island sources declined (Allen and Johnson, 1997). Geochemical evidence from other islands in the southern Cooks also indicates that Aitutaki adzes were not transported to more distant localities (Sheppard et al., 1997; Walter, 1998; Weisler et al., 1994), probably because of the adequate but less than ideal quality of Aitutaki's basalts. Thus the scale of transport was relatively local, with demand not extending beyond Aitutaki, despite the limited availability of adze-quality rock on nearby islands like Ma'uke, Mitiaro, and Atiu.

5.4. Some issues and further model development

As with many archaeological analyses, there is an array of processes which can potentially produce similar outcomes, the problem of equifinality. This is especially the case with indices like those developed here. The Cortex and Volume Ratios serve as proxies for past behaviours, which can be further evaluated and tested with other data. They also help identify information that is poorly

controlled, as demonstrated above. Some of the additional processes which could have affected our test results include scavenging from older deposits, variation in knapper skill, and stone working related to activities other than adze production. The possibility that materials from earlier occupations were mined by later site occupants is considered unlikely. This is because Zone F was effectively capped by the Zone E storm deposit and there are no stratigraphic indications that materials deposited in Zone F were accessed by subsequent shelter occupants (Allen, 1992; Allen and Morrison, 2013).

Another possibility is that variation in ratios across the three strata could reflect differences in knapper abilities. At Moturakau, the relatively small number of broken preforms which remain in the analysed assemblage (compared to the estimated number removed; approximately 63 from all zones) suggests a high success rate, rather than inexperienced knappers (Cleghorn, 1986). Further, significant differences in skill seem unlikely given the distance of Moturakau from the Aitutaki mainland and the costs of supporting specialized adze manufacturing activities on this tiny islet where water and food supplies are limited. Finally, the major variables of interest for this analysis (total observed and expected cortical surface area and volume to quantify artefact transport) would not be substantially affected by variation in knapper skill.

Finally, it is possible that a portion of the Moturakau assemblage was produced through adze rejuvenation activities rather than preform production. The presence of three non-local polished flakes from the analysed sample suggests that adze rejuvenation did take place at Moturakau but, beyond the polished flakes, there is little other evidence for rejuvenation activities. This suggests that rejuvenation activities were uncommon at Moturakau. Other factors which could affect reduction processes, and possibly the measures developed here, include temporal differences in intended forms, variation in reduction strategies, and/or preferences for complete versus partial cortex removal. The uniformity of our results across the three temporal units suggests these factors have not affected our analytical ratios. All of the foregoing factors could be further evaluated through a technological analysis of the Moturakau assemblage and comparisons with finished adze assemblages from consumption sites.

6. Conclusions

It is not easy to archaeologically track artefact transport but the methods presented here provide one avenue to do this by using early stage adze manufacturing assemblages. On their own, the Cortex and Volume Ratios can provide a measure for the under- or over-representation of cortex and volume resulting from artefact transport from quarry/workshop assemblages. They also can provide an estimate for the number of preforms produced and transported from these assemblages. Although these measures offer important artefact transport information, it is the overall combination of data and methods with the Cortex and Volume Ratios that can provide considerably more detailed information on artefact production, artefact transport and interaction. By combining these ratios with radiocarbon chronologies it is possible to generate measures for the frequency of artefact transport patterns over time while, combined with geochemical techniques, measures for the scale of artefact transport are also possible.

The Cortex and Volume Ratio methods are not only applicable to early stage quarry and/or workshops with stratified assemblages but also to other Polynesian assemblages such as those produced from different raw material forms (e.g., dyke stone), as well as assemblages from non-stratified quarry assemblages and habitation sites. Many quarry sites in Polynesia do not contain stratified adze manufacturing assemblages (e.g., Cleghorn, 1982). However, like the first archaeological applications of the Cortex Ratio to non-stratified surface stone artefact scatters in western New South Wales (Douglass et al., 2008; Holdaway et al., 2008), it is still possible to calculate the under- or over-representations created by artefact transport and, with the modifications developed here, the number of preforms transported. Assemblages from habitation sites will be characterised by different compositions to quarry sites (e.g., less cortical and less volume) but, if the original nodule size and shape are modified to account for the nodule form introduced to the sites (i.e., reduction at habitation sites may begin from preforms), it will be possible to apply a modified version of this method. The same is true for assemblages produced from different raw material forms. If the original nodule size and shape are modified to reflect these different forms, it will be possible to apply the methods presented here. Applications like these will also serve to further refine the method.

Ultimately, building on previous applications (Dibble et al., 2005; Douglass et al., 2008; Holdaway et al., 2008), the successful experimental and archaeological application of the Cortex and Volume Ratios to a Polynesian adze manufacturing assemblage shows that the method is flexible and capable of quantifying artefact transport patterns from technologically diverse assemblages.

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References

Allen, M.S., 1992. Dynamic Landscapes and Human Subsistence: Archaeological Investigations on Aitutaki Island, Southern Cook Islands (Ph.D. dissertation). University of Washington, Seattle. University Microfilms International, Ann Arbor.

Allen, M.S., Huebert, J.M., 2014. Short-lived plant materials, long-lived trees, and Polynesian ^{14}C dating: considerations for sample selection and documentation. Radiocarbon 56, 257–276.

Allen, M.S., Johnson, K.T.M., 1997. Tracking patterns of ancient interaction: recent geochemical studies in the southern Cook Islands. In: Weisler, M.I. (Ed.), Prehistoric Long-distance Interaction in Oceania: an Interdisciplinary Approach. New Zealand Archaeological Association Monograph, Auckland, pp. 111–133.

Allen, M.S., McAlister, A., 2013. Early Marquesan settlement and patterns of interaction: new insights from Hatiheu Valley, Nuku Hiva Island. J. Pac. Archaeol. 4, 90–109.

Allen, M.S., Morrison, A.E., 2013. Modelling site formation dynamics: geoarchaeological, chronometric, and statistical approaches to a stratified rockshelter sequence, Polynesia. J. Archaeol. Sci. 40, 4560–4575.

Ayres, W.M., Fitzpatrick, S.M., Wozniak, J., Goleš, G.G., 1998. Archaeological investigations of stone adzes and quarries on Easter Island. In: Lee, G., Stevenson, C.M., Morin, F.J. (Eds.), Easter Island in Pacific Context, South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia. Easter Island Foundation, Los Osos, pp. 304–311.

Bayman, J.M., 2003. Stone adze economies in post-contact Hawai'i. In: Cobb, C.C. (Ed.), Stone Tool Traditions in the Contact Era. University of Alabama Press, Tuscaloosa, pp. 94–108.

Berman, H., 1939. A torsion microbalance for the determination of specific gravities of minerals. Am. Mineral. 24, 434–440.

Best, S., 1977. The Maori adze: an explanation for change. J. Polyn. Soc. 86, 307–338.

Buck, P.H., 1927. The material culture of the Cook Islands (Aitutaki). Mem. Board Maori Ethnol. Res. 1. New Plymouth.

Cleghorn, P.L., 1982. The Mauna Kea Adze Quarry: Technological Analyses and Experimental Tests (Unpublished Ph.D. thesis). The University of Hawaii, Hawaii.

Cleghorn, P.L., 1984. An historical review of Polynesian stone adze studies. J. Polyn. Soc. 93, 399–421.
Cleghorn, P.L., 1986. Organisational structure at the Mauna Kea adze quarry complex, Hawaii. J. Archaeol. Sci. 13, 375–387.
Collerson, K.D., Weisler, M.I., 2007. Stone adze compositions and the extent of ancient Polynesian voyaging and trade. Science 317, 1907–1911.
Di Piazza, A., Pearthree, E., 2003. Diversity of Islands, Diversity of Site Types: Archaeological Research in the Cook Islands (Unpublished report). Ministry of Cultural Development, Cook Islands.
Dibble, H.L., Schurmans, U.A., Iovita, R.P., McLaughlin, M.V., 2005. The measurement and interpretation of cortex in lithic assemblages. Am. Antiq. 70, 545–560.
Ditchfield, K., 2011. Stone Artefact Transport and Human Movement in Pleistocene South-western Tasmania (Unpublished M.A. thesis). The University of Auckland, Auckland.
Douglass, M.J., 2010. The Archaeological Potential of Informal Lithic Technologies: a Case Study of Assemblage Variability in Western New South Wales, Australia (Unpublished Ph.D. thesis). The University of Auckland, Auckland.
Douglass, M.J., Holdaway, S.J., 2011. Quantifying stone raw material size distributions: investigating cortex proportions in lithic assemblages from western New South Wales. Tech. Rep. Aust. Mus. 23, 45–57.
Douglass, M.J., Holdaway, S.J., Fanning, P.C., Shiner, J.I., 2008. An assessment and archaeological application of cortex measurement in lithic assemblages. Am. Antiq. 73, 513–526.
Duff, R., 1959. Neolithic adzes of eastern Polynesia. In: Freeman, J.D., Geddes, W.R. (Eds.), Anthropology in the South Seas. Thomas Avery and Sons, New Plymouth, pp. 121–148.
Holdaway, S., Fanning, P., 2014. Geoarchaeology of Aboriginal Landscapes in Semi-arid Australia. CSIRO Publishing, Collingwood.
Holdaway, S., Shiner, J., Fanning, P., Douglass, M., 2008. Assemblage formation as a result of raw material acquisition in western New South Wales, Australia. Lithic Technol. 23, 1–16.
Holdaway, S.J., Stern, N., 2004. A Record in Stone: the Study of Australia's Flaked Stone Artefacts. Aboriginal Studies Press, Canberra.
Holdaway, S., Wendrich, W., Phillipps, R., 2010. Identifying low level food producers: detecting mobility from lithics. Antiquity 84, 185–194.
Kahn, J.G., 1996. Prehistoric Stone Tool Use and Manufacture at the Ha'atuatua Dune Site, Marquesas Islands, French Polynesia (Unpublished M.A. thesis). The University of Calgary, Calgary.
Kahn, J.G., Sinton, J., Mills, P.R., Lundblad, S.P., 2013. X-ray fluorescence analysis and intra-island exchange in the Society Island archipelago (Central Eastern Polynesia). J. Archaeol. Sci. 40, 1194–1202.
Kirch, P.V., Mills, P.R., Lundblad, S.P., Sinton, J., Kahn, J.G., 2011. Interpolity exchange of basalt tools facilitated via elite control in Hawaiian archaic states. PNAS 109, 1056–1061.
Leach, H.M., 1993. The role of major quarries in Polynesian prehistory. In: Graves, M.W., Green, R.C. (Eds.), The Evolution and Organisation of Prehistoric Society in Polynesia. New Zealand Archaeological Association Monograph, Auckland, pp. 33–42.
Lin, S.C.H., Douglass, M.J., Holdaway, S.J., Floyd, B., 2010. The application of 3D laser scanning technology to the assessment of ordinal and mechanical cortex quantification in lithic analysis. J. Archaeol. Sci. 37, 694–702.
McAlister, A.J., 2011. Methodological Issues in Geochemical Characterisation and Morphological Analysis of Stone Tools: a Case Study from Nuku Hiva, Marquesas Islands, East Polynesia (Unpublished Ph.D. thesis). The University of Auckland, Auckland.
Mills, P.M., Lundblad, S.P., Field, J.S., Carpenter, A.B., McElroy, W.K., Rossi, P., 2010. Geochemical sourcing of basalt artefacts from Kaua'i, Hawaiian Islands. J. Archaeol. Sci. 37, 3385–3393.
Mintmier, M.A., 2007. Adze production in Maui: analysis of lithic materials from the west rim of Haleakalā. Hawaii. Archaeol. 11, 3–17.
Mintmier, M.A., Mills, P.R., Lundblad, S.P., 2012. Energy-dispersive x-ray fluorescence analysis of Haleakalā basalt adze quarry materials, Maui, Hawai'i. J. Archaeol. Sci. 39, 615–623.
Parker, D.J., 2011. The Complexity of Lithic Simplicity: Computer Simulation of Lithic Assemblage Formation in Western New South Wales, Australia (Unpublished M.A. thesis). The University of Auckland, Auckland.
Phillipps, R.S., 2012. Documenting Socio-economic Variability in the Egyptian Neolithic through Stone Artefact Analysis (Unpublished Ph.D. thesis). The University of Auckland, Auckland.
Plog, F., 1977. Modelling prehistoric exchange. In: Earle, T.K., Ericson, J.E. (Eds.), Exchange Systems in Prehistory. Academic Press, New York, pp. 127–140.
Rolett, B.V., Conte, E., Pearthree, E., Sinton, J.M., 1997. Marquesan voyaging: archaeometric evidence for inter-island contact. In: Weisler, M.I. (Ed.), Prehistoric Long-distance Interaction in Oceania: an Interdisciplinary Approach. New Zealand Archaeological Association Monograph, Auckland, pp. 134–148.
Sharp, A., 1960. Pacific adzes and migrations. J. Polyn. Soc. 69, 39–42.
Shennan, S., 1997. Quantifying Archaeology. University of Iowa Press, Iowa City.
Sheppard, P.J., Walter, R., Parker, R.J., 1997. Basalt sourcing and the development of Cook Island exchange systems. In: Weisler, M.I. (Ed.), Prehistoric Long-distance Interaction in Oceania: an Interdisciplinary Approach. New Zealand Archaeological Association Monograph, Auckland, pp. 85–108.
Spitzer, A., 2005. Lithic Economies and Self-sufficiency: Stone Tool Production and Consumption in a Late Prehistoric Community of Moloka'i, Hawaii (Unpublished B.A. Honours thesis). The University of Queensland, Brisbane.
Atoll Research Bulletin 190. In: Stoddart, D.R., Gibbs, P.E. (Eds.), Almost-Atoll of Aitutaki: Reef Studies in the Cook Islands, South Pacific. Smithsonian Institution, Washington D.C.
Turner, M.T., 1992. Make or Break: Adze Manufacture at the Tahanga Quarry (Unpublished M.A. thesis). The University of Auckland, Auckland.
Turner, M.T., 2000. The Function, Design and Distribution of New Zealand Adzes (Unpublished Ph.D. thesis). The University of Auckland, Auckland.
Turner, M.T., 2011. The role of reworking in New Zealand adze technology. In: Marwick, B., Mackay, A. (Eds.), Keeping Your Edge: Recent Approaches to the Organisation of Stone Artefact Technology, BAR International Series. Archaeopress, Oxford, pp. 57–70.
Turner, M.T., Bonica, D., 1994. Following the flake trail: adze production on the Coromandel East Coast, New Zealand. N. Z. J. Archaeol. 16, 5–32.
Walter, R.K., 1998. Anai'o: the Archaeology of a Fourteenth Century Polynesian Community in the Cook Islands, vol. 22. New Zealand Archaeological Association Monograph, Dunedin.
Walter, R., Sheppard, P.J., 1996. The Ngati Tiare adze cache: further evidence of contact between west Polynesia and the southern Cook Islands. Archaeol. Ocean. 31, 33–39.
Weisler, M.I. (Ed.), 1997. Prehistoric Long-distance Interaction in Oceania: an Interdisciplinary Approach. New Zealand Archaeological Association Monograph, Auckland.
Weisler, M.I., 1998. Hard evidence for prehistoric interaction in Polynesia. Curr. Anthropol. 39, 521–532.
Weisler, M.I., 2002. Centrality and the collapse of long-distance voyaging in East Polynesia. In: Glascock, M.D. (Ed.), Geochemical Evidence for Long-distance Exchange. Bergin and Garvey, London, pp. 257–273.
Weisler, M.I., 2008. Tracking ancient routes across Polynesian seascapes with basalt artifact geochemistry. In: David, B., Thomas, J. (Eds.), Handbook of Landscape Archaeology. Left Coast Press, Walnut Creek, pp. 536–543.
Weisler, M.I., Kirch, P.V., Endicott, J.M., 1994. The Mata'are basalt source: implications for prehistoric interaction studies in the Cook Islands. J. Polyn. Soc. 103, 203–216.